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ABSTRACT

The differences between the media of books and computers lies partly in the way in which information is displayed, rather than in the content of the information itself. The term "legibility" denotes how specific physical characteristics of a display affect visual fatigue, reading speed, and ultimately comprehension. Some of these physical components include illumination, color, the printing surface, spacing, typography, and illustrations. There are, however, several features of the computer that affect legibility in totally new ways. For example, in a computer-reading environment, one reads "printing" not "print." There is only one surface for the display of information, the cathode ray tube. In addition, both the presentation of new text and the elimination of the old occur during the reading process. Furthermore, a new physical dimension has been added, the dimension of time. Dynamic legibility is a source of concern because of the nearly limitless ways of controlling the third dimension, the temporal features of text and graphic displays. Though the previous research on legibility provides some foundation for making decisions on how to display text and graphics, new research is needed to address the question of when to display text and graphics. (HOD)

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THE CONSTRUCT OF LEGIBILITY IN THE READING ENVIRONMENT OF A MICROCOMPUTER

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THE CONSTRUCT OF LEGIBILITY
IN THE READING ENVIRONMENT OF A MICROCOMPUTER

In recent years there has been tremendous interest in using computers as a tool in nearly every profession. Hundreds of journal articles, research papers, and reports have been written on different applications for the modern microcomputer. Much of this research on computers has tended to be one sided. Ben Schniederman (1980) in the introduction to his book, Software Psychology, reflects upon this:

> I requested a computerized literature search for journal articles with keywords such as "programming", "programming psychology", or "cognitive psychology". The 61 documents described by the search all described the application of computers to psychology. Not one document mentioned application of psychology to computer science.

The situation described by Schneiderman applies equally well to existing research in the area of reading and computer science. One the largest reviews of literature done on these combined fields is Computer Applications in Reading (Mason, Blanchard, & Daniel, 1983). Only a few of the articles, papers, and dissertations which they cite address

the application of reading research to computer science. Instead the research has focused on how computers can be used to assist in providing reading instruction. The use of computers to aid in providing reading instruction is a topic very worthy of consideration and should not be downplayed. Nonetheless, if there is to be true cross-disciplinary research between the fields of computer science and reading then it should be equally possible to apply the findings of reading and psycholinguistics to the development of computers and computer programs. This paper will attempt such an application.

THE MICROCOMPUTER AS A READING ENVIRONMENT

A logical place to begin dealing with the reading process in computer sceince is in the way text and graphics are displayed by the computer. The differences between the media of books and computers lies partly in the way in which information is displayed, rather than in the content of the information itself. Moreover, the physical presentation of content is a matter of practical and immediate concern to computer programmers. All physical display on a computer, must be specifically and carefully constructed through the use of programming language. An efficient use of display commands such as "print", "hlin", or "vtab" can be critical to the total storage required for a given program and to the speed at which the program operates. However, far more than

economy, it is the comprehensibility of the display which is of greatest importance to the program developer. Display that is imprecise or poorly formated will negatively effect the readers' comprehension of the text and increase the chance of user errors. Therefore one aspect of reading that is of critical concern to a programmer or system analyst is the legibility of the text and graphics displayed by the computer.

Legibility is an area of reading for which there is an extensive base of research literature. Some of this literature is directly applicable to reading from a cathode ray tube display. Some of it is not. Yet, if we have learned anything from media theorists such as Marshal McLuhan (1967), it is that every medium has certain characteristics which inherently become part of the content of the message itself. The goal of this paper is to review known legibility factors as they relate to the reading environment of computer displays, and to explore new aspects of legibility which are present due to the unique features of this medium. It is hoped that in doing so, some guidelines for the control of computer hardware and computer displays can begin to be developed.

The cathode ray tube is the surface used for the display of information generated by the microcomputer. The display device may be a monitor, a CRT specifically designed for computer generated output, or it may simply be a television

set which has been adapted so as to receive the signal generated by the computer. Both televisions and monitors may be further subdivided into two categories; color and monochrome displays. The monochrome displays may be of several types: green text on black, amber text on black, and white text on black.

Terminology

The term "legibility" denotes how specific physical characteristics of a display effect visual fatigue, reading speed, and ultimately comprehension. Miles Tinker (1963), one of the most experienced researchers on the subject of legibility, suggests that this term is more appropriate than "readability", in that this latter term is too often confused with "readability formulas" as opposed to the comprehensibility of text. For reasons which will be discussed later, the term "static legibility" may be a more appropriate term for these factors, given the features of a computer-reading environment.

STATIC LEGIBILITY FACTORS

In his authoratative book *The Legibility of Print*, Tinker (1963) delineates some of the physical components of printed material, and discusses their effects upon reading comprehension, reading speed, and visual fatigue. These

components are:

1. Illumination
2. Color
3. The Printing Surface
4. Spacing
5. Typography
6. Illustrations

Our discussion of legibility need not be limited to these factors. Nonetheless, if we are to apply existing reading research to the computer-reading environment, then each of these factors should be carefully reviewed.

1. Illumination

The previous research on the illumination of printed material in books is to a great extent inapplicable to our discussion of reading from a CRT. This is because previous studies were concerned with the nature of light reflected from the printed page. However, a CRT is itself a source of light, rather than a reflector of light. Certain conclusions from previous studies, however, may have limited applicability. Kuntz and Sleight (1949) concluded that adequate lighting for seeing details was between 10 and 30 foot-lamberts. For readers with less than perfect visual acuity adequate lighting was between 30 and 40

foot-lamberts. There is a need to substantiate these finding for the CRT, where the light from the CRT itself is added to that present in the room. However, if their finding is substantiated, it may be adviseable for readers with poor visual acuity to increase illumination through the adjustment of the brightness control on the CRT or through room lighting.

Another aspect of illumination which is worth reviewing is the factor of brightness contrast. In a study in 1959 Tinker found that with a constant 25 foot-candle illumination, reading speed was gradually reduced as brightness contrast was reduced. When the brightness contrast fell below 60% greater illumination was required. This finding is of particular relevance to computerized displays. Most monitors and TV sets have an easily accessible "contrast" control which allows the user to adjust brightness. Tinker's research suggests that caution will need to be exercised in setting this control so that brightness contrast is not reduced beyond an acceptable range. It also suggests that even at maximum brightness, insufficient brightness contrast can reduce reading speed and perhaps contribute to visual fatigue.

Only the effects of insufficient brightness contrast have been studied to date. However, because the CRT is itself a light source, the other end of the spectrum may need to be investigated as well. Is there such a thing as excessive

brightness contrast? Will very strongly illuminated letters against a completely unlit background create such an excessive brightness contrast that visual fatigue is increased? The question is a new one, and as yet no studies of this question were uncovered in this literature review.

2. Color

Since the early 1930's there has been a steady increase in the use of colored paper for printed material. Luckiesh and Moss (1938) conducted a detailed investigation of legibility with paper and ink in a variety of colors. They concluded that the paper color (background) did not significantly effect visibility, speed of reading, or visual fatigue when the ink was black. Luckiesh (1923) has ranked the following combinations of print and background as follows:

1 black on yellow
2 greeen on white
3 red on white
4 blue on white
5 white on blue
6 black on white
7 yellow on black
8 white on red
9 white on green
10 white on black
11 red on yellow
12 green on red
13 red on green

Luckiesh's conclusions are severely weakened because he did not report in detail the experiments by which he reached

these conclusions. Nor does he give relative distances between the groups. The data are only ordinal in nature. Still, the findings of Luckiesh are generally consistent with a number of studies which followed and which used a variety of dependent measures. Preston, Schwankl, and Tinker (1932) found blue on white, black on yellow, and green on white to be highly legible using the distance method. Sumner (1932), also using the method of perception at a distance, found blue on gray, black on gray, and black on yellow to be highly perceptible.

To what extent are these finding important and relevant to the reading environment of a computer? First, it must be granted that the use of color for both background and print is a legitimate concern of software designers given recent developments in computer technology. Nearly all microcomputers on the market have the capability to display a variety of colors for both text, background, and graphics. As microcomputers have increased in sophistication the number of available colors has progressively increased until now, new models can literally display hundreds of colors.

The findings of Luckiesh and others may have some general relevance. However, one observation by Tinker suggests that the previous studies are not likely to be of great help in determining what are the best color combinations of print and background for a computer. The high reflectance of white and yellow paper creates a high brightness contrast.

Thus, a combination such as black on yellow is perceived as being more legible than red on blue not because of color contrast but because of brightness contrast. This sensible observation by Tinker has important implications for our discussion. Due to the physical construction of most color monitors and TV's there is a tremendous difference between the relative brightness of colors on paper, and colors on the screen. The intensity of any singled dot on the screen (pixel) can be increased or decreased electronically without any change in the hue. Hue and brightness are independently controllable factors in the reading environment of the computer. Given this, the optimal color combinations may be very different than for paper, depending upon how the brightness contrast is controlled.

3. The Printing Surface

All previous studies on the effect of the printing surface upon reading have, for the most part, assumed that the printing surface was some type of paper. Given this assumption, the primary concerns were the texture of the paper, the thickness of the paper, the absorbancy of the paper, and the amount of glare produced by the paper. However, the reading surface in a computer-reading environment is not paper, it is glass or plexiglass. Of the above mentioned factors only the last, glare, would seem to be a relevant concern. This is because a CRT surface is

even more subject to glare than paper.

Tinker (1965) concluded after several studies that most readers "...obviously dislike reading print on highly glossy paper." In contrast, Luckiesh and Moss (1938) found little variation in visibility due to the glossiness of the paper. His findings do not truly dispute Tinker's argument, in that Luckiesh made his measurements in extremely good, diffused lighting. Tinker's argument is that only when lighting is poorly diffused does the glossiness of the paper surface cause sufficient glare to impede reading. Studies by Paterson and Tinker (1940) and Stanton and Burtt (1935) found that very glossy paper had no negative effect. However, Paterson and Tinker found in several studies that combining the effects of print size, font, and surface with the factor of poor lighting produced results which were cumulative. One combination reduced reading speed by as much as 20%.

These few studies would, at the very least, lead one to suspect that in a computer-reading environment surface glare could indeed reduce reading efficiency, especially when lighting is poorly diffused. A key factor in lighting may be the placement of the CRT screen. A CRT is nearly always a vertical reading surface, unlike books which can be held in a variety of positions. Light entering a room from a vertical plane such as a window can create a great deal of glare on a vertical surface. Overhead lighting may reduce

it.

Computer manufacturers have attempted to solve the problem of glare by physically redesigning the CRT screen. Three approaches have been used. One solution has been to apply a polarized plastic film similar to that used in sunglasses. Another technique has been to serate the surface of the screen so that light coming in from an angle is reflected away from the user. A third technique has been to design CRT's so that the screens can be angled or tilted to avoid the glare. It is likely that all of these techniques are effective in reducing glare, however, formal studies of their effectiveness have not appeared in the reading research literature.

4. Spacing

The many factors involved in a page's spatial arrangement have become standardized for most paper-reading environments. Spacing factors such as margins, page size, and word spacing are treated as a constant by most readers and publishers. This does not mean that they are equally appropriate in a computer-reading environment.

Page Size

In general, the factor of page size would appear to be a matter of aesthetics. Books exist in an enormous range of

sizes, and though some sizes have become standardized, there is no data to indicate that any particular size is easier to read than any other. At first glance it would appear that screen size would also be a matter of aesthetics. Yet, there are certain factors involved in the physical construction of cathode ray tubes which tend to make the range of sizes considerably more limited. Most CRT's range in size from 9 inches (diagonal measure) to 24 inches. While some manufacturers have managed to create TV screens much larger and smaller than this, there are construction factors which greatly add to the cost. Furthermore, modern large projection TV's tend to be less clear than regular CRT's due to dispersion and reduced luminosity. In most TV's or monitors the size and clarity of text is directly related to the size and clarity of the cathode ray tube as a whole. Therefore excessively small CRT's may lead to excessively small print. This has been a common complaint of many of the "portable" computers which have used extremely small CRT's and as a result display extremely tiny characters. No studies were uncovered which suggest what the optimal size for a CRT is, but it does seem likely that there is both an upper an lower limit to the size of a screen.

Margins

Publishers have long argued that using adequate margins is important in any printed text. However, this is not supported in the research literature. A study by Paterson

and Tinker (1940) showed that eliminating the margins did not significantly effect reading speed. One exception to this finding is for the gutter margin. The gutter margin is that which borders the binding of the book. Tinker (1957) argued that the curvature of the page in towards the spine of the book obscured the print. He conducted an experiment in which students read from text mounted on an eight-inch cylinder so that the text was curved. He found that the curvature both reduced reading speed and perception at a distance. As a result he suggested that the gutter margin be increased sufficiently to avoid curvature.

Though CRT's do not have spines like books, they are, nonetheless, subject to curvature. On some CRT's the text tends to curve as it approaches any of the edges of the screen. Curvature may also occur quite commonly as a result of improper horizontal and vertical alignment of the screen. If the work of Tinker and Patterson is correct, then it is reasonable to suspect that such curvature and distortion of text could significantly reduce reading performance. One possible means of circumventing this problem may be to design computers so that all text occurs within a border created on the CRT. Several current models of microcomputers (Atari, Radio Shack) currently display text in this fashion.

The Spacing of Words

Some of the most solidified conventions in publishing

involves the use of space within a text. We always separate each word by one character space and each sentence by two spaces. Despite the wide acceptance of these spacing standards there is considerable evidence which suggests that there are better ways of spacing words within a text. A number of researchers (North & Jenkins, 1951; Klare, 1957; Epstein, 1967; Anglin and Miller, 1968; Cromer, 1970; and Mason and Kendal, 1978) have suggested alternative means of spacing texts. Most of these researchers have suggested that text be grouped spatially into chunks. Some have suggested grouping the text according to the syntactic structure, while others have suggested grouping the text according to semantic structures. There was substantial disagreeement among these researchers as to the most appropriate means of segmenting text and its effects upon comprehension. However, one finding that was consistant across several studies was that the chunking of text into groups in a fashion that was inconsistent with meaning or phrase structure served to reduce comprehension (Epstein, 1967; Klare, 1957).

This finding has specific relevance to computerized displays. One of the most common features of many word processors is the automatic justification of text. In most cases whole character justification is used. What the computer does is justify out the text by inserting extra character spaces in between certain words. What is significant is that the placement of the characters is done

through the use of an algorithm which does not take into consideration the natural phrase boundaries and meaning of the text. As a result the text is chunked into segments which are irrelevant and sometimes contrary to the natural flow and meaning of the text. The previous research on spacing suggests that this practice is likely to interfere with text comprehension.

The whole issue of text justification may be relatively suspect. Modern word processing programs have made the complete justification of text on both left and right margins as easy as pushing a button. As a result many word processing operators have begun justifiying the right margins of almost anything they type. Zachrisson (1965) has suggested that unjustified text is better for less proficient readers. Spencer (1969) in reviewing the literature on typography concludes that, at the very least, unjustified text does not reduce legibility. Though justified text may be aesthetically pleasing, its use, from a reading standpoint, should be viewed as highly suspect.

5. Typography

Most publishers have direct control over the typographic layout of the text. This means they must make decisions as to the actual typefaces or fonts to be used, the size of the type, and whether or not to use upper and lower case

letters. Though many of these aspects of print have become somewhat standardized, there is nonetheless a good deal of variation. The ability to select different fonts and typesizes has become increasingly important to users of microcomputers. Microcomputers have improved dramatically in the last few years in their capabilities for displaying and combining different fonts and typesizes. New micros such as the MacIntosh from Apple can instantaneously change the size or font of any word on the screen. Complex typesetting configurations which use to take a typesetter hours can be completed in less than a minute. These new capabilities create new headaches for those using these sophisticated word processors. Which combination of type size and font is most effective? When should upper case letters be used? The research literature may provide some answers.

Upper and Lower Case Print

Watts and Nisbet (1974) in their excellent work, Legibility in Children's Books, make the following conclusions about the use of upper case versus lower case lettering:

1. Lower case print is read faster and is preferred more by fluent readers than is upper case.
2. Beginning readers do not read upper case text faster than lower case text.
3. Upper case letters are more readily identified

than lower case letters when presented in isolation.

4. Upper and lower case letters are equally legible when placed in a word context.

5. Upper case letters do not provide as much of a cue to overall word shape as do lower case letters.

These findings have a good bit of relevance to reading from computer displays and for reading from much of the hard copy generated by computers. For years many of the display terminals used by main frame terminals have outputed text in only upper case. The reason for this was primarily a matter of engineering. A lower case character set took up additional space in memory and added somewhat to the complexity of programming. However, as computers have increased in sophistication upper case only displays are becoming more scarce. Most modern microcomputers have the ability to display both upper and lower case letters. One limitation, however, is that many computers cannot be programmed in both upper and lowercase. While the computer will accept a lowercase letter in a word processing mode, it will not properly interpret a lowercase letter in programming mode. As a result, the programmer is forced to work in all upper case.

The research cited by Watts and Nisbet argue strongly against limiting displays to only upper case characters. Adults do not prefer them and they may reduce both reading

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and writing speed. The research also suggests that if a lowercase character set is to be used, it will be more effective if it is a "true" lowercase character set, one with both ascending and descending characters. This is because ascending and descending characters help to create a contour which may be useful in word identification.

Size of Type

One unit of measurement in the printing profession is the "point". A point is roughly equivalent to 1/72 of an inch measured vertically. Standard type for most adults is somewhere between 9 and 12 points. Childrens type may range as high as 24 points. As has already been mentioned the actual unit for measuring display with a cathode ray tube is the pixel, with the distance between pixels on a standard 12 inch CRT being approximately 1/24 of an inch. There are a given number of pixels built into any cathode ray tube. The density of the pixels may very greatly from CRT to CRT. With most computers each letter is composed of a set of pixels within a pre-defined matrix. A typical matrix might be 7 pixels high by 8 pixels wide. The density of pixels for a given screen is a constant. If the size of the matrix for a given character is increased, then the number of lines that can be printed on the page is decreased. The spacing between lines increases relative to the change in the size of the matrix.

What is the optimal size for a font. Early researchers such

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as Griffing and Franz (1896) concluded that type sizes lower than 10 point led to visual fatigue. Paterson and Tinker (1929, 1940) found that 11 point type was read faster and preferred more. In reviewing this literature, however, Watts and Nisbet accurately point out that type size should not be considered separate from line length and leading. Buckingham (1931), for example, did an extensive series of studies in which type size was looked at in combination with length of line and leading. He also made separate measures of both reading speed and comprehension for each of these combinations. He found that 12 point type with a 14 and 1/2 pica line length and 3 point leading was read most rapidly. However, an 18 point type set in a 24 pica line length with 3 point leading ranked 2nd in comprehension but only 14th in speed. Overall, the 12 point type ranked relatively high for both dependent measures.

It should be kept in mind that the size of type for a computerized display is a function of the size of the CRT being used. On a 19 or 26 inch TV the usual type size is considerably larger than 18 point type. Also the leading on most displays is not something the user can control. The size of the leading is determined by the number of pixels assigned the top and bottom of a matrix. Given a set matrix, any increase in the size of the leading decreases the number of pixels that form the character itself.

Typeface

There have been a number of empirical studies on the legibility of particular mechanical typefaces. Some of the features of typefaces which have been found to effect legibility are: the relative weight or thickness of the strokes composing the letters, the amount of white space enclosed within a letter, the length of ascenders and descenders, the use of serifs, and the overall design of the typeface.

Most of these features have limited applicability to typefaces generated by computers. Smooth, straight lines do not truly exist in computerized fonts. Whatever impression of smoothness that one gets is a result of the optical effect of bleeding which occurs whenever a point of light disperses outward from a source. As the density of the addressable pixels in computer displays continues to increase there is a steady improvement in the apparent smoothness of most fonts. However, most microcomputers still use fonts which are made up of a very small pixel matrix (7x9, or 8x11). On larger monitors the dot by dot makeup of the letters is quite discernable. The limitation of the smaller matrix makes the use of "serifs" and other fine typefaces impossible on most micros.

What may be a relevant concern is the use of white space within specific fonts. Research by Burt, 1959; Tinker, 1965; and Spencer, 1969 showed that the greater the relative area of the enclosed space within a letter, the greater its

legibility. Given the limits of dot matrix displays, it is tempting to increase the boldness of a character by lighting more of the points which border the enclosed space. However, if this previous research is correct, then any effort to make the print more bold in this manner will reduce legibility rather than improve it. Though more costly in terms of total space, it may be more appropriate to expand a character outward from the enclosed space than inward if additional boldness is desired.

Typographic Cues

The physical design of specific fonts, though perhaps a factor in visual fatigue, is not likely to have significant effects upon comprehension of text in most reading situations. Man has shown himself to be enormously adept at adjusting to a variety of graphic symbols systems (Gelb, 1965). How these symbols are used, however, may be significant where semantic processing is concerned. The use of typography to provide cues to meaning is an age-old practice. Special fonts such as italics, or bold faced characters, underlining, and color coding have all been used extensively as cues to meaning in printed material. There is a solid theoretical justification for this use. Early experimental work has shown that by isolating an item to be learned against a homogenious background, recall of that item is fascilitated (Wallace, 1965). This effect, often referred to as the von Restorff effect, offers a plausible expanation for the utility of typographic cues. Additional

support comes from cognitive researchers who have suggested that typographic cues can serve as "perceptual organizers", making the text perceptually more salient (Rothkopf, 1971; Ausabel, Novak, and Hanesian, 1974). Despite these strong theoretical justifications for the use of typographic cues, research supporting their effectiveness is rather mixed (Browning, 1976; Glynn, 1978).

Glynn draws two very useful conclusions from the review of the literature on typographic cues. First, that there is little evidence of a positive overall effect for typographic cues provided in the text. Any positive effect of experimenter provided typographic cues is probably limited to the intentional (cued) information in the text. Moreover, this improved retention probably comes at the expense of the non-cued information. Second, typographic cues are probably most effective when they are generated by the readers themselves, provided that there is no time restriction on the reader. The justification being that in normal studying situations the real value of typographic cues such as underlining and notetaking may lie in the fact that the activity itself causes the learner to spend more time with the reading material and process it more completely (Wittrock, 1974; Annis and Davis, 1978).

To what extent are these conclusions on typographic cuing applicable to the computer-reading environment. To begin with it must be noted that microcomputers have tremendously

increased the feasability of making extensive use of typographic cues. It is now possible with modern microcomputer based word processing programs to instantly make typographic modifications of any segment of text in a matter of seconds. This is true for both the on-line materials or the paper copy generated by the word processor. Consequently the argument that typographic cues are too costly and time consuming for publishers (Fowler and Barker, 1974) can no longer be justified.

It is probably not wise to expect a great deal of facilitation for typographical cues since their effect appears to be limited only to those sections of text which are cued. Nonetheless, if it is true that they serve as perceptual organizers, then they may have particular utility in computer-reading environments. This is because many traditional typographic cues to text structures are absent in common computer-reading situations such as word processing. During word processing text is usually scrolled by the reader. The text is often not chunked spatially into pages nor are there usually page numbers. In situations where one is editing or reading documents of several pages typographic cues such as underlining, inversing, or bold headings may provide a perceptual organization to a document, given the absence of other cues.

The issue of user generated versus text provided typographic cues may, on the other hand, be especially problematic in

many microcomputer reading situations. In most programs the user is not permitted to access or mark in any fashion the text display. All interaction with the program is usually predetermined as a matter of protection or programming efficiency. The research suggests that in designing future reading environments, some provision be made to allow the user to typographically mark important segments of text. There are a number of ways this might be done. Underlining is often problematic due to the design of most character generators. However, it may be possible to permit highlighting through the use of an inverse function common to many computers. Regardless of the method, reading research would suggest that such cues, if made accessible, could signifcantly improve legibility.

6. Illustrations

No discussion of legibility would be complete without mention of the effects of pictures and graphics. This topic, especially in respect to children's books, has been hotly debated for some time. There have been a number of excellent reviews of this contraversial literature. Though there is still considerable disagreement on the topic certain conclusions can be drawn.

The vast majority of children's textbooks and children's computer programs contain a high volume of illustrations.

Since illustrations are the norm, then the burden of proof would seem to lie upon those who do not advocate the use of illustrations with children's texts. Some of the most convincing evidence against the use of illustrations comes from S. J. Samuels. Samuels (1967) found that when children were asked to read aloud individual words with or without illustrations, performance on the word identification task was poorer when illustrations were present. These findings have been replicated by a number of other researchers (Brayn, 1969; Harris, 1967; Harzem et al., 1976). Samuels has concluded that when a young reader is exposed to a task in which there are two types of cues to a particular response, the reader will use that cue which requires the least effort. For many beginning readers, naming the picture is easier than attempting to decode a word. As a result many will make no attempt to decode the word at all. This could result in a lack of decoding skills and impede the development of sight vocabulary. Even when the task is not oral identification, but rather total comprehension, Samuels (1970) is skeptical of the use of illustrations. For example, he points out that Miller (1938) and Weintraub (1960) both compared basal readers with and without illustrations. Both experimenters found no significant differences in comprehension. Other studies by Vernon (1953, 1954) and Koenke (1968) also found that illustrations did not significantly improve text comprehension for young readers.

As strong as these finding are, there is, nonetheless, a large amount of literature which firmly supports the use of illustrations. One extensive study on the use of illustrations was conducted by Denberg (1976). Denberg found, contrary to Samuels, that first graders read more words correctly (two word pairs) if the words were also represented by a picture. The discrepancy of this finding with those previously discussed may be due to the nature of the illustrations which were used. In Denberg's experiment the illustrations used did not contain any extraneous information and were directly related to the text. In contrast Samuels (1970) states in his review that "...preference was given to those studies in which pictures were used as adjuncts." Consequently, in those studies in which facilitation was found, the pictures may frequently have contained information which was peripheral to the point of the text. This suggests that it is not the pictures in and of themselves which is critical, but rather the information which the pictures reveal. Apparently, the more informative the pictures are the more likely they are to support rather than hinder the comprehension of the text.

Several studies support this conclusion. Peeck (1974) conducted a study in which two types of pictures were used; those which sensibly fit the text, and those which were totally incongruent with the text. Peeck found that more information was recalled by those exposed to congruent pictures than those exposed to incongruent pictures.

Schallert (1980) reports a study in which text with pictures were found to be more effective than text without pictures. A dependent measure was used which made it possible to look at comprehension across many segments of the text. The results showed that the overall positive effect could be traced directly to improved performance just on those portions of the text which related to the illustration and not on portions which were irrelevant to them.

Most of these studies lead to the same conclusion. Illustrations are only likely to be supportive of text in those cases in which the pictures contribute information which is relevent to the content of the text. In other circumstances, their effect may be negligible, and in some situations, such as the one word decoding activities used by Samuels, irrelevant information from pictures may actually detract from the learning of decoding skills and sight vocabulary. Studies by Royer and Cable (1975) go on to suggest that the facilitation of text comprehension is dependent upon the extent to which the illustrations serve as concrete examples which can act as assimilative structures for new information. The classic studies by Bransford and Johnson (1972) provide other supporting evidence for this.

Some texts may be more suited to the use of illustrations than others. Shallert (1980) found that pictures are likely to help readers learn from written material if they contain

information that relates directly to spatial or temporal concepts in the text. In situations where the content is strongly organized around spatial information, pictures may actually be superior to text (Kolers, 1973). The work of Paivio (1971) suggests that the facilitating effect of pictures in such circumstances may be based upon different ways of cognitively processing information. He argues that the pictures enhance the development of mental images and in doing so lead to a greater depth of processing.

There are a number of factors which limit the amount of information which a computerized illustration may contain. One obvious limitation of computerized illustrations is space. A screen on most microcomputers can display only about half a page of text or less. Because of this space limitation it is not often possible to separate illustrations from the text by any great amount of space. If large illustrations are used, there will be very little room at all for text. The obvious solution to this problem would be to use small, finely drawn illustrations. This too, however, is not possible given the dot matrix construction of most cathode ray tubes. The pixel density for most graphics is the same as for the text, and consequently extremely fine lines are simply not possible.

Another constraint on many computerized displays is a lack of full color display capabilities. For example, the Apple II computer is able to display only about six colors

accurately. As yet most microcomputers cannot approximate the variety of colors that can be employed in most magazines and textbooks. Furthermore, there are some stringent limitations to the extent to which shading can be used. Most current models of microcomputers cannot control the relative brightness for a given color. There is no bright red or dull red- just red. Finally, most cathode ray tubes often do not display colors with complete accuracy. A slight misadjustment of the color controls on a CRT can turn orange to red, green to blue, etc.

Overall these technical limitations should not be viewed as particularly problematic. The research shows that it is the information represented by the picture which is critical rather than physical aspects of the picture itself. Except in those few situations where color or pictoral detail is critical to the meaning of the picture, there is no reason to believe that the picture will not be effective, especially if it relates directly to the text. At the same time, the research argues strongly against the idea of using pictures for pictures sake. The extensive use of graphics as a means of making a program more attractive (and more marketable) is highly questionable. The research suggests that pictures used in this fashion will do little to improve reading comprehension, and may serve to distract poor or beginning level readers.

THE CONSTRUCT OF DYNAMIC LEGIBILITY

In the previous discusion a number of essential differences between paper-reading environments and computer-reading environments have been discussed. The discussion to this point has attempted to determine the extent to which earlier findings on legibility will apply when the medium under consideration is a computer. This review has not precluded the possibility that there may be aspects of legibility which are totally reserved to the medium of the computer. There are, in fact, several features of this new medium which effect legibility in totally new ways. These will now be examined.

The Computer as a Multi-dimensional Environment

A book is essentially a two-dimensional reading environment. The page has height and width, as do the characters composing the text. The use of shading, and perspective can give letters and graphics a sensation of depth, a third dimension, but it is only an impression. The paper remains two-dimensional; the ink permanent.

Compare this with a computer-reading environment. The screen of a CRT has height and width, as does a book, but there is an additional dimension. In a computer-reading environment one reads "printing" not "print". This is not just a subtle distinction. When reading from a computerized

display one does not flip page by page through a permanent collection of printed material. Instead there is only one surface for the display of information, the CRT. As a result, that surface must be constantly refreshed with new information once the old information is completed.

It is significant is that both the presentation of new text and the elimination of the old occur DURING the reading process. A whole screenful of letters may be presented in the blink of an eye, or one letter may be displayed each second. The words may be printed all at once or in blocks, with presentation lags between each letter, word, sentence, or paragraph. Once on the screen, the words and letters may again appear or dissappear. Letters and words may move suddenly to different parts of the screen. The letters may not only change position, but size, shape, color, or brightness as well. Text may flash on and off or simply become inversed. Illustrations may also appear or dissappear from the screen. They can become animate and move across or around the screen. In short, every aspect of legibility previously discussed can no longer be treated as a constant. A new physical dimension has been added, the dimension of time.

Dynamic legibility is a matter of practical concern for computer programmers and computer designers, just as is static legibility. Static legibility is a source of concern primarily because of the limitations of conventional CRT's

for the display of information in two dimensions. Dynamic legibility is a source of concern because of the nearly limitless ways of controlling the third dimension, the temporal features of text and graphic displays. The computer programmer must be concerned not only with HOW to display information, but WHEN to display information.

Dynamic Legibility Factors

As with many media, initial users of the medium of microcomputers failed to take advantage of the unique new possibilities of carefully timed displays. Instead, screens were replaced as a whole, just as if one were going from page to page. Rather than using the special qualities of the medium, displays were based on the medium that preceeded it, books. In the last few years, however, programmers have begun to use time selectively in changing screen displays.

Graphic Animation

The manipulation of temporal features was first applied to graphics. By changing the shape and position of a graphic over time a picture can be made to appear animate. This type of animation was the basis for many early microcomputer programs. Primarily graphics were used for games and simulations. As computers and computer programmers developed the ability to combine text with graphics on the same screen, changes in graphic displays began to be

correlated with the text.

It has already been mentioned that the nature of CRT construction limits the amount of detail that can be put into a computerized graphic. This lack of detail reduces the amount of information that the graphic can transmit. By changing a graphic over time, however, it is possble to add to the amount of information a graphic conveys. Not only can the illustration carry information, but the motion or action of the graphic can convey information. A good exmple of this can be found in a simple piece of animation used in an early instructional program called "Prefixes" from MECC. In this exercise the objective is to teach the use of the prefix "un". The student is shown the word "load". Then a graphic of a truck moves across the screen. In unloads a pile of dirt, and at the same time the word on the screen changes from "load" to "unload".

Text Animation

The animation of graphics has become a standard feature of nearly all educational simulations. Motion, however is not limited simply to graphics. In word processing programs there is extensive physical movement of words and letters. In word processing programs, words automatically change location whenever new words are inserted or old words are deleted. If one is inserting a segment of text into a document, as each letter is added, all of the text to the

right of the point of entry is shifted one letter to the right. Whole screens or segments of text can rapidly scroll up or down to any point in the text the user wishes to see. In short, during word processing the text is always in a state of motion.

Other aspects of the text may change as well. For example, most microcomputers have what is known as a flashing mode. This is usually a simple programming command that causes successive reversals in the text from white on black to black on white display. The figure ground reversals occur every few seconds and make the text appear to flash. It is frequently used as a dynamic typographic cue in programs to focus the attention of the user upon an important instruction such as a warning.

Presentation Delays

One of the simplest ways of using time in computer displays is through print delays. It is a simple matter to present sections of text such as paragraphs so that there is a delay between each section as it appears on the screen. The length of any delay can be used to provide information about the relationship between the segments of text being displayed. For example one might present a word, pause for a few seconds and then present the definition. The temporal break in the presentation serves to delineate the text into two meaningful sections. This technique is similar in many

repects to visual information mapping as described by Horn (1969).

Delays in presentations, however, are not always intentional or controlled. Sometimes delays are created when the computer is required to perform an extensive function, such as searching through a file, prior to the next display. Just as delays may serve to provide useful information as to the relationships within a text, this type of delay may in some situations interfere or misdirect comprehension. Consequently, the designer must not only be consider the use of delayed text presentation in terms of positively contributing to the meaningful interpretation of text, the designer must also attempt to find ways to avoid comprehension disruption through unavoidable processing delays.

Animation, flashing, scrolling, and print delays are just a few of the possible temporal manipulations that must be considered by a designer of computer displays. As hardware continues to improve the number and complexity of such manipulations will continue to increase. For example, with the recent models of microcomputers it is possible to prioritize movement of graphics on the screen so that some graphics will appear to have moved in front of or behind others. Though the screen remains two dimensional, this particular type of combined motion gives the screen a tremendous feeling of depth much like holographic images.

The possibilities for using this technique to add to the instructional qualities of a display have as yet gone untouched, so new is the hardware that permits it. Nonetheless, it is safe to assume that any technique for display will eventually be experimented with by ambitious programers. What is clearly lacking is a body of research upon which to base such experimentation.

Research Relating to Dynamic Legibility

Dynamic legibility is the product of a new medium. Consequently, it is not surprising that there is little or no research upon the effects of dynamic displays upon reading performance. There is, however, a limited amount of research which bears indirectly upon this topic. This research comes from a variety of areas; studies on the effects of educational television, studies on perception in reading, and studies on the general nature of human perception.

Certainly, the single most relevant study to our topic is one conducted by O'Bryan and Silverman (1972) of the Children's Television Workshop. These researchers studied the eye-movement patterns of 60 children enrolled in a reading clinic. They measured students who were good readers, poor readers, and non-readers. The subjects read from a video screen which contained both text and videotaped images and which was accompanied by sound. They found that

the good readers were able to easily process the written material without being distracted by the moving images on the screen. Slow readers, however, were often distracted by the motion on the screen and frequently failed to process past the first two or three letters of the text. Non-readers tended to look somewhat randomly about the screen, though focusing mostly upon the graphic action scenes.

The medium of instruction used by O'Bryan & Silverman is not completely comparable to that of a computer-reading environment. The graphics were of a much higher quality than is usually possible to display using a microcomputer, unless it is interfaced with video disk or video tape. Nonetheless, the results of their study are generally in keeping with previous studies on the use of illustrations with good and poor readers and were confirmed in a second series of studies on educational television by Mock (1976). As mentioned earlier, Samuels has suggested that the reader will use whatever cue requires the least effort in a comprehension task. He also points out that for skilled readers, the decoding task has become automated and so requires little or no conscious effort (LaBerge & Samuels, 1974). Consequently we would expect good readers to make use of the text under such conditions, since decoding is for them an automated response requiring little or no conscious effort. On the other hand, slower readers would find it easier to use the graphics as the primary cue to

comprehension.

The Problem of Distraction

The problem of distraction, as outlined by O'Bryan & Silverman is crucial to the issue of dynamic legibility. The designer of a dynamic format must always question whether or not any screen motion adds or detracts from the usability of the display. It has already been suggested that motion, if used in conjunction with the text, can add to the informative content of the display. At the same time, this advantage must be balanced against the increase in distraction to the reader. An important consideration would be the span of reading. The greater the span, the greater the room for distraction. Studies by McConkie (1976) and Raynor (1975) bear directly upon this. The fact that the medium for their research was a computer, adds to the impact of their studies to this discussion. Their research suggested that motion which occurs beyond 12 character spaces to the right of the fixation point may go undetected in a computer-reading environment. This is assuming that our sensitivity to motion is on the same plane with our sensitivity to shapes and the distinctive features of letters. However, perceptual research would seem to bring this assumption into question.

In the book Sight and Mind Lloyd Kaufman (1974), a noted

researcher in the field of perception, states that "...it is a well-known fact that movement in the periphery (of the retina) is more salient than movement in the center." Kaufman cites several perceptual studies (Auber, 1886; Walis, 1963; Troxler, 1804) which support this conclusion. Given these studies it may not be safe to assume that motion occuring on the periphery of vision during reading will go undetected. The research suggests the contrary, that humans are particularly sensitive to motion within a visual field, especially on the periphery. As a consequence, distraction caused by motion must be of particular concern to the designer of CRT displays.

Normal Visual Processes

The problem of distraction is not the only concern when dynamic changes occur on a screen. An interesting question is what happens to normal visual processes such as regressive eye-movements in reading. It has long been know that regressive eye-movements are common during normal reading activities (Gibson & Levin, 1975). They allow for brief rereading of critical information which may help to interpret or disambiguate current semantic processing. A study by Wanat (1971) has shown that readers are able to direct the regressive movement back to those specific areas of the page which contain the relevant information.

Wanat's research strongly suggests that readers have a type of spatial memory for the text they have just read. Otherwise they would be unable to locate the appropriate point for their regressive fixation. If this is the case, then what happens when the page dynamically changes format as the reading is occuring. Such changes occur frequently with the scrolling of text off of a screen, or in word processing situations. Can readers restructure visual memory as the screen is being restructured or will the change in the screen disrupt spatial memory and lead to inaccurate regressive eye-movements. This is but one of many questions on screen dynamics which remains unanswered.

Dynamic Typographical Cues

Though it appears likely that dynamic computer displays may misdirect some readers away from the text processing, it is also possible that the use of dynamics could be used in a positive sense to attract the reader's attention to critical elements of a text. It has already been suggested that typographic cuing may enhance the retention of targeted information. It is reasonable to expect that dynamic typographical cuing may even do more to focus attention on such information. Whether or not these same techniques would fascilitate comprehension once visual attention had been focused on them is another matter.

The use of any typographic cue may be enhanced in other ways in a computer-reading environment. One of the primary weakness of most cuing systems and adjunct study aids has been that they do not work equally well for all readers. Many good readers have sufficient skills and background knowledge to comprehend text structure without the use of such cues. For such readers the use of cues may actually interfere with text processing (Hartley and Davies, 1976). The computer, however, is a dynamic, interactive environment. Instead of the reader having to adjust to the text, it is possible for the text to adjust to the reader. For example, if a student was failing to comprehend key ideas in a passage, as measured by interspersed questioning, typographic cues and illustrations could be added to subsequent segments of the text. If the student was proceeding well no typographic enhancements need be added. A similar technique involving the ongoing adjustment of readability factors has already been shown to be highly successful in improving comprehension for poor readers (L'Allier, 1980).

SUMMARY

In this manuscript I have attempted to determine how research on reading applies to the issue of creating effective microcomputer displays, a matter of great concern to those in the field of computer science. In doing so both

traditional and non-traditional concepts of legibility have been delineated. From the blend of these concepts a new construct of legibility has emerged. It is a construct which defines the factors of legibility within the confines and attributes of the specific medium under consideration. A complete model of the factors involved in legibility must be based upon all attributes present in the medium under consideration. Because microcomputers have added a distinctive new physical dimension to display, the dimension of time, a whole new set of attributes must be considered.

Previous research on legibility, though somewhat dated, does seem to provide some guidelines for improving the legibility of computer displays, especially where comprehension may be directly effected. Previous research relative to factors such as visual fatigue and reading speed may be somewhat more suspect due to the different physical characteristics of cathode ray tubes and because of the limited instruments used for measuring those factors in the early studies. Though the previous research on legibility provides some foundation for making decision on HOW to displays text and graphics, the question of WHEN to display text and graphics has gone almost untouched. A tremendous amount of research will be needed in order to determine a basic set of guidelines for the temporal configuration of computer displays.

Though a great deal of research remains ahead, there are,

nonetheless, two good reasons for believing that future research on legibility promises to be productive. First, the ease with which display features can be adapted will permit the rapid design and implementation of materials for the purpose of experimentation. The computer cannot only create a variety of display formats in a matter of minutes, but it can be used to collect data on the effectiveness of those displays with extreme accuracy. Second, the need to create a single standard for legibility has been removed. It is no longer necessary to determine what is the optimal format for ALL students for ALL texts. All of the factors effecting legibility can be adapted by the computer to meet the needs of a particular student interacting with a particular text. This will require that extensive research be done to determine where legibility factors interact with individual differences. Once this is determined, however, the promise of improving the quality of computer displays is very, very bright.

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